Uranium Stabilization through Polyphosphate Injection:

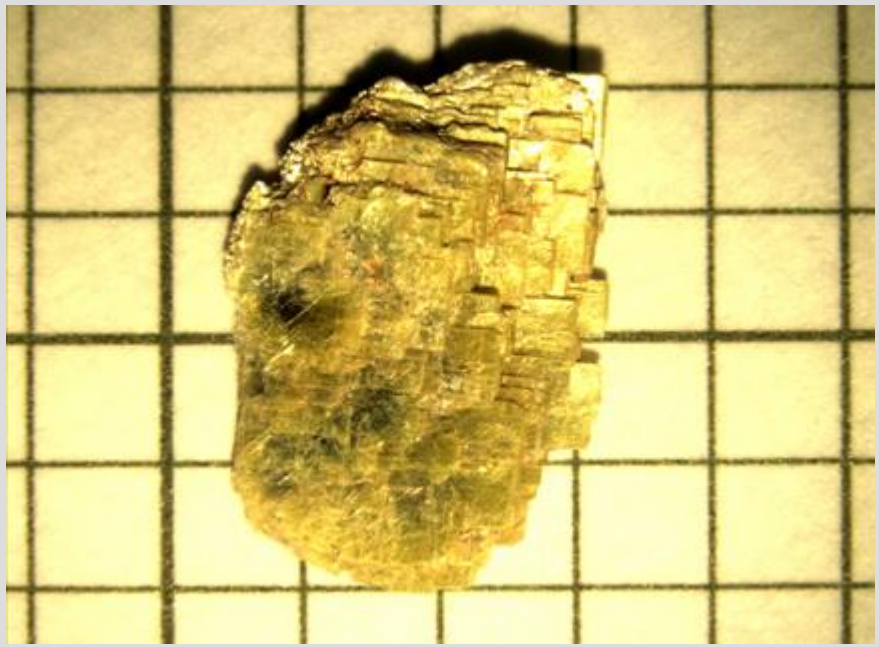
Field Site

August 29, 2007

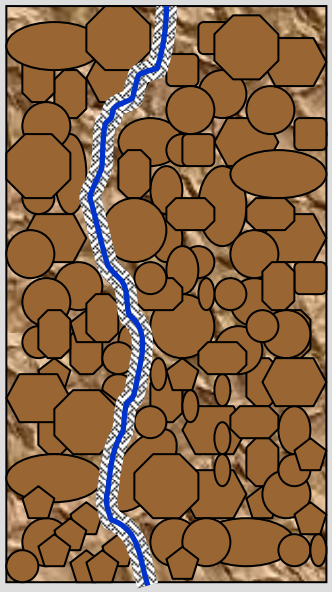
John Fruchter (PM)
Dawn Wellman (PI)
Vince Vermeul (TL)

Uranium-Phosphate (Autunite) Minerals

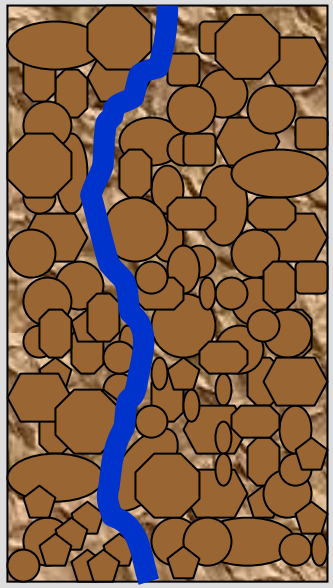
- Very low solubility.
- Formation does NOT depend on changing the redox conditions of the aquifer.
- Not subject to reversible processes such as reoxidation or desorption.



Challenges to Phosphate Amendments: Rapid Precipitation Kinetics



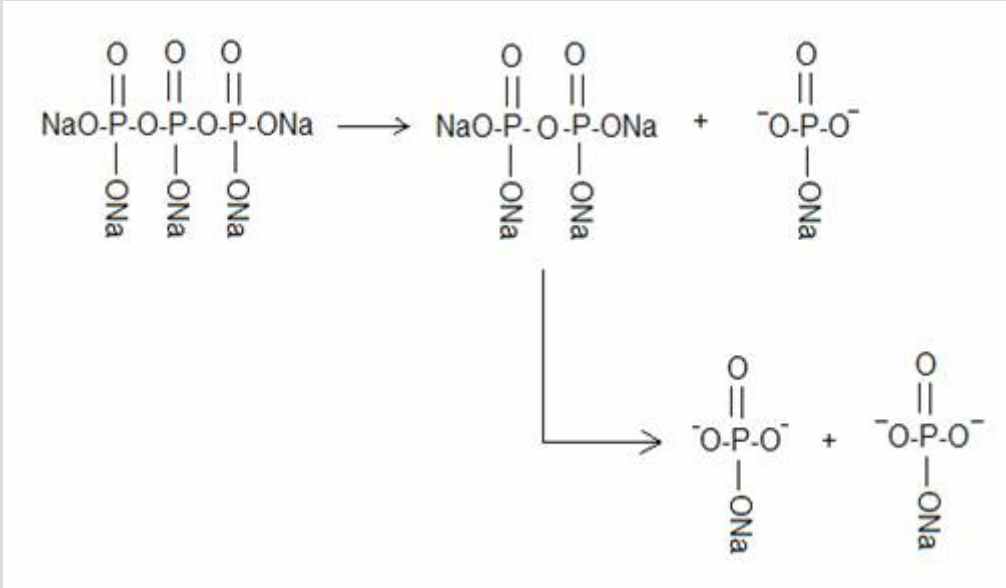
- Injection of monophosphate molecules results in rapid flocculation and precipitation of phosphate phases
- Sharp decrease in hydraulic conductivity.



- Polyphosphate precludes rapid precipitation
- No measurable decrease in hydraulic conductivity

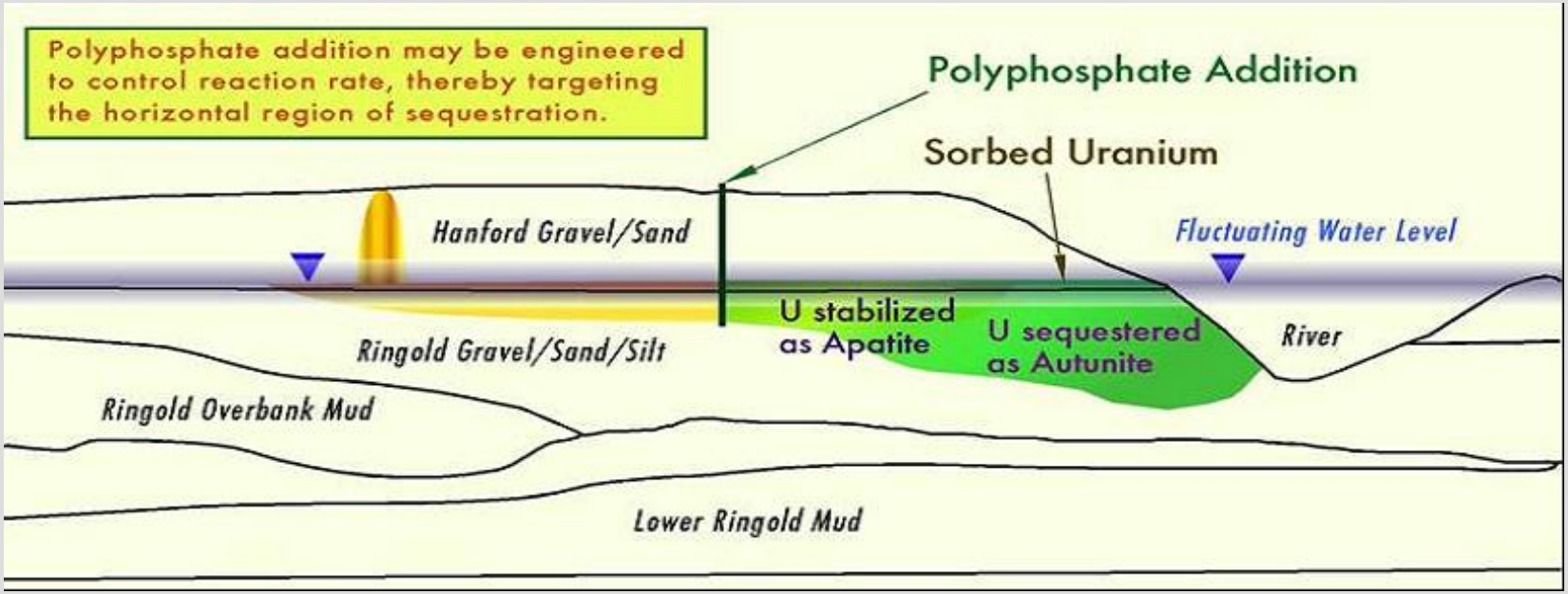
Solution to Deployment Challenges: Use of Long-Chain Polyphosphates

- Slow reaction with water to yield orthophosphate
- Rate of hydrolysis is related to chain length
  - Time release - Controllable kinetics based on to polymer length
- Rate of phosphate mineral formation is directly related to the rate of polyphosphate hydrolysis.
  - Direct treatment of uranium
  - Provides immediate and long-term control of aqueous uranium



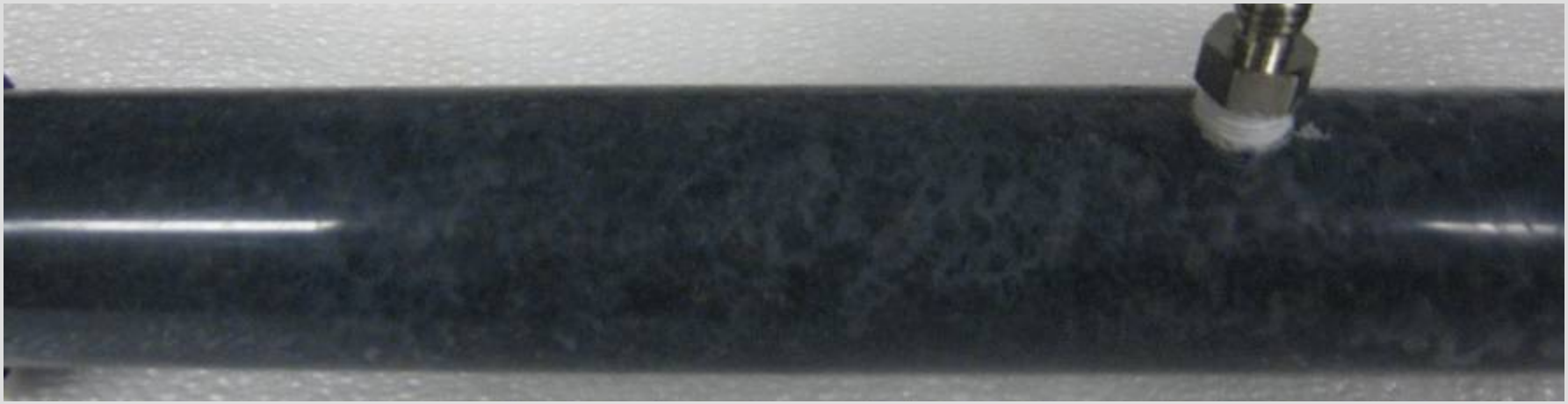
Polyphosphate amendment can be tailored to delay formation of autunite and apatite.

Deployment of Phosphate Amendment for In-Situ Immobilization of Uranium



- Injection of soluble polyphosphate
- Lateral plume treatment
- Uranyl phosphate mineral (autunite) formation
  - Immediate sequestration
- Apatite formation
  - Sorbent for uranium
  - Conversion to autunite
- Enhancement of MNA

Uranium Column Testing

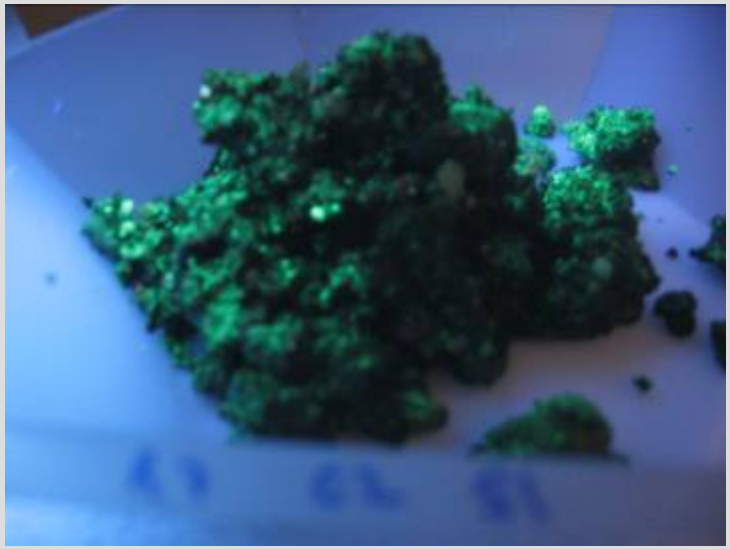


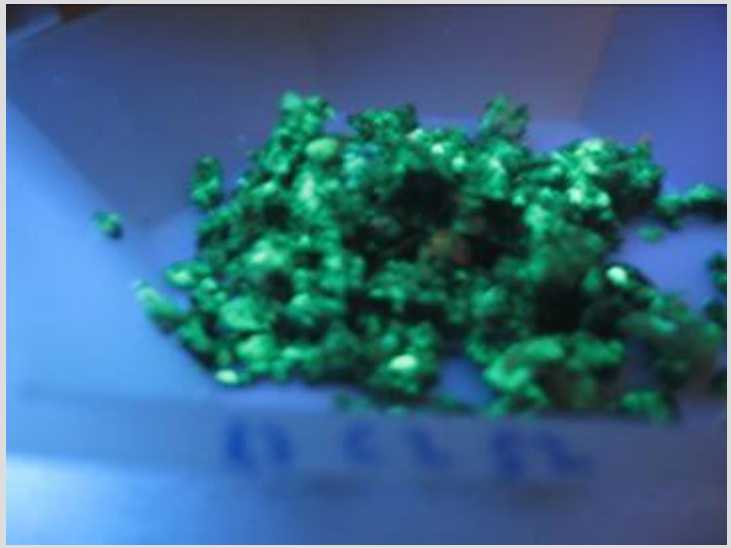
Total $[P]_{aq}$ = 5.26 x 10^{-2} M Tripoly $[P]_{aq}$ = 8.77 x 10^{-3} M

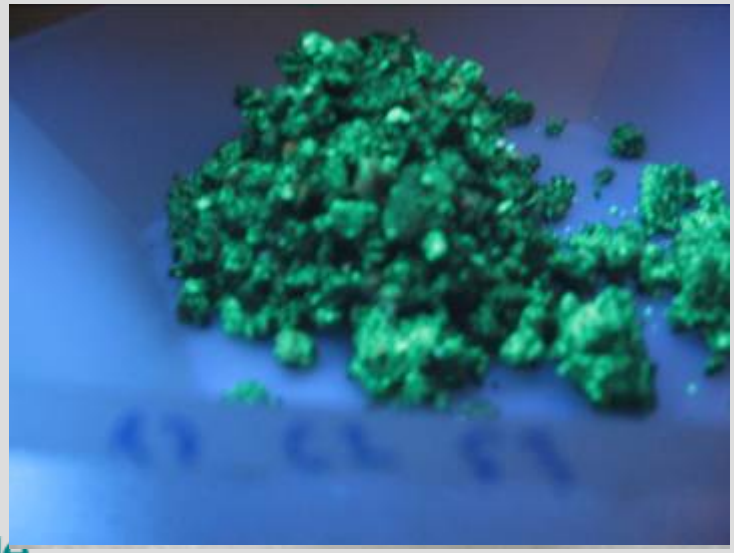
Pyro $[P]_{aq}$ = 6.58 x 10^{-3} M Ortho $[P]_{aq}$ = 1.32 x 10^{-2} M

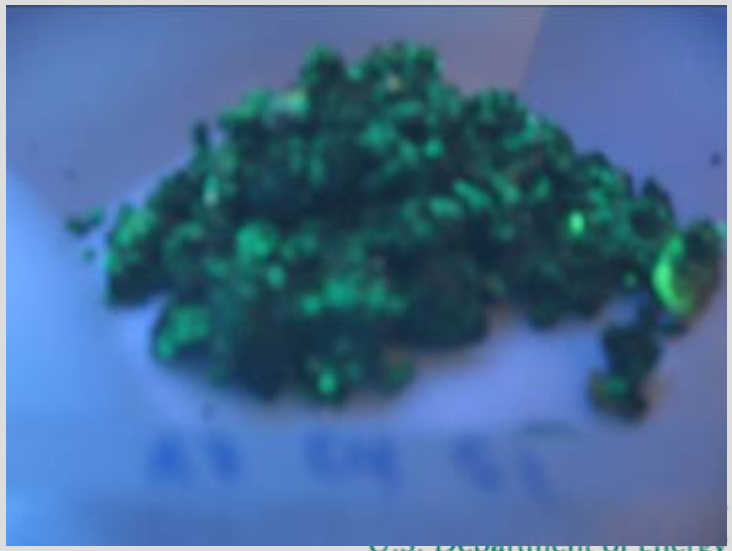
$[Ca]_{aq}$ = 9.98 x 10^{-2} M pH = 7 RT = 56 min PV = 52 mL PV = 1 Ca/ 1P

Post-Test Preliminary Analysis

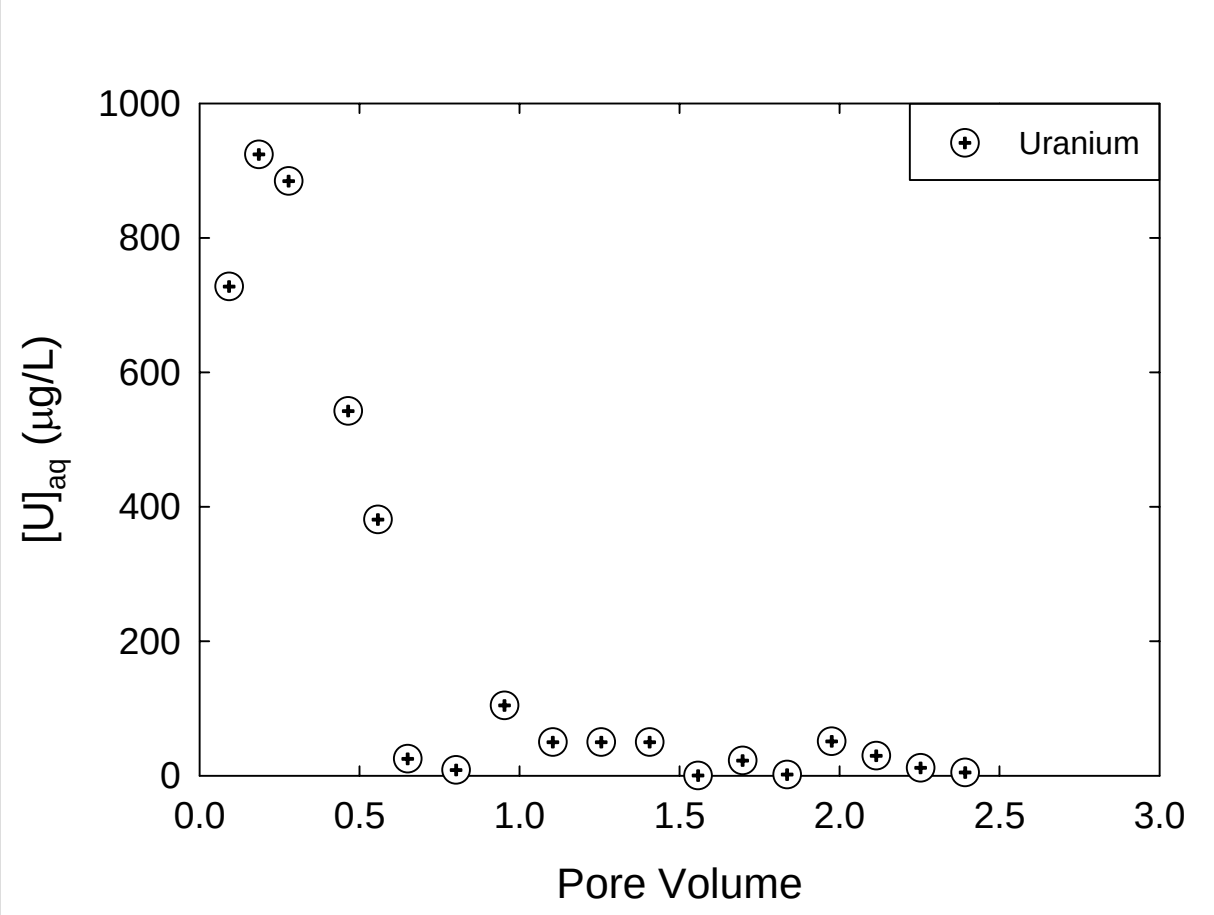








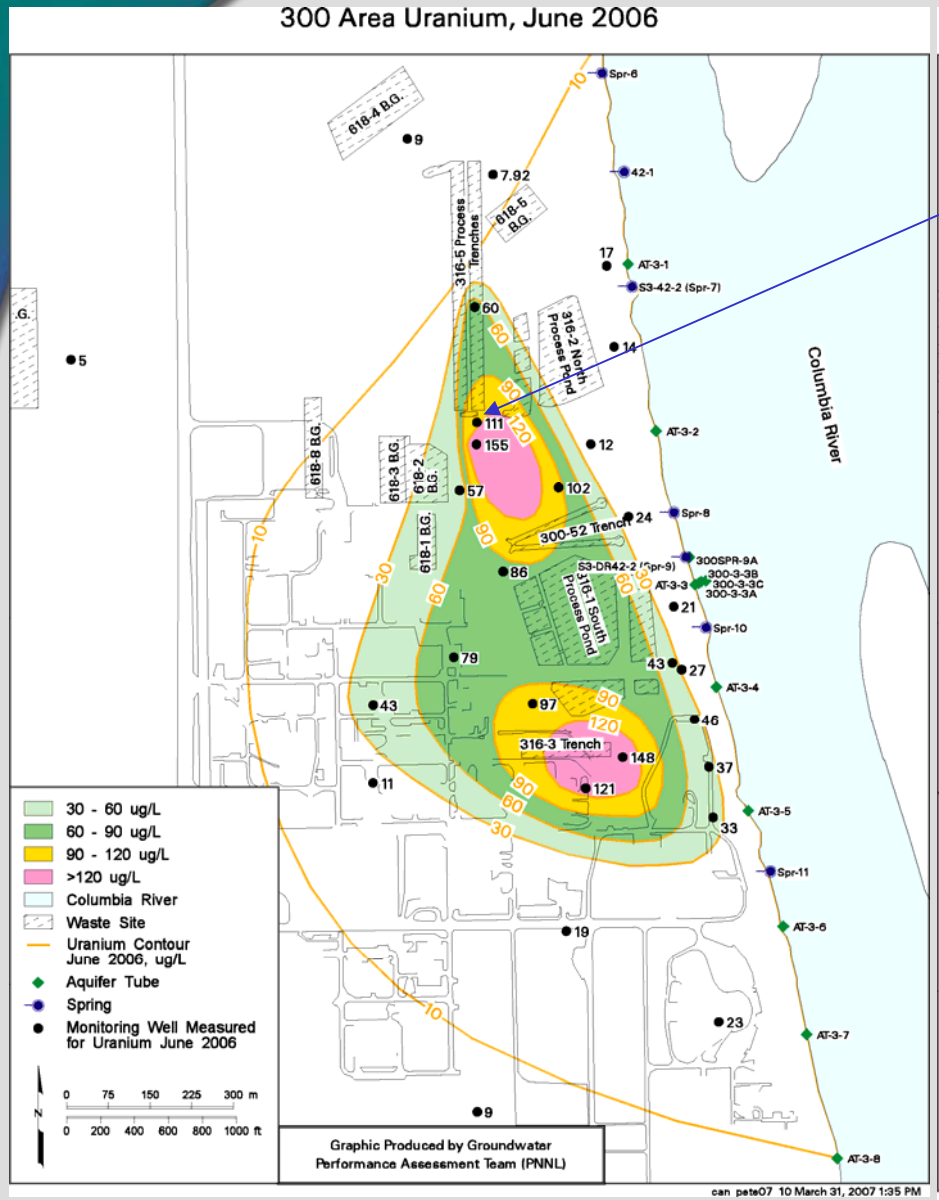
Aqueous Uranium During Treatment

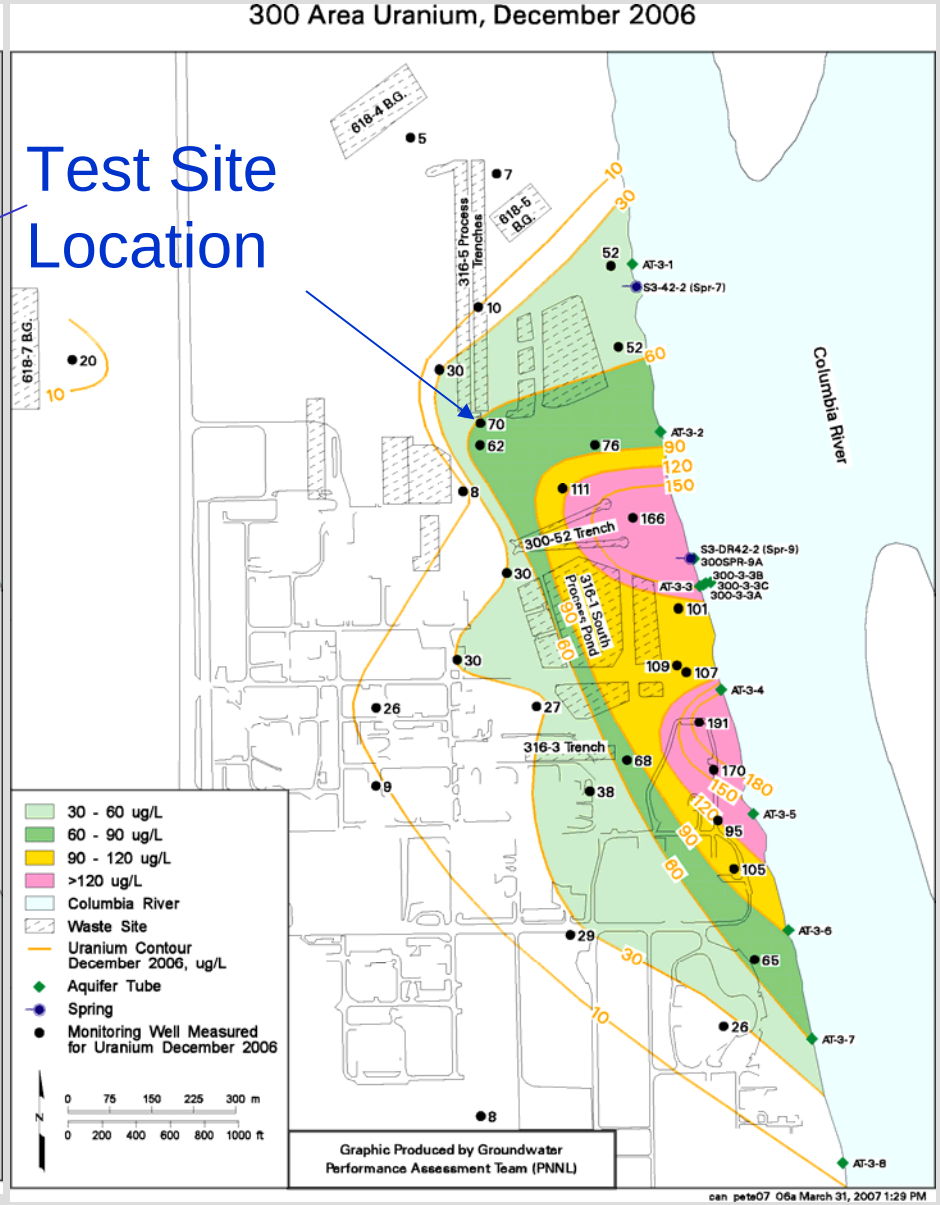


Treatability Testing Activities

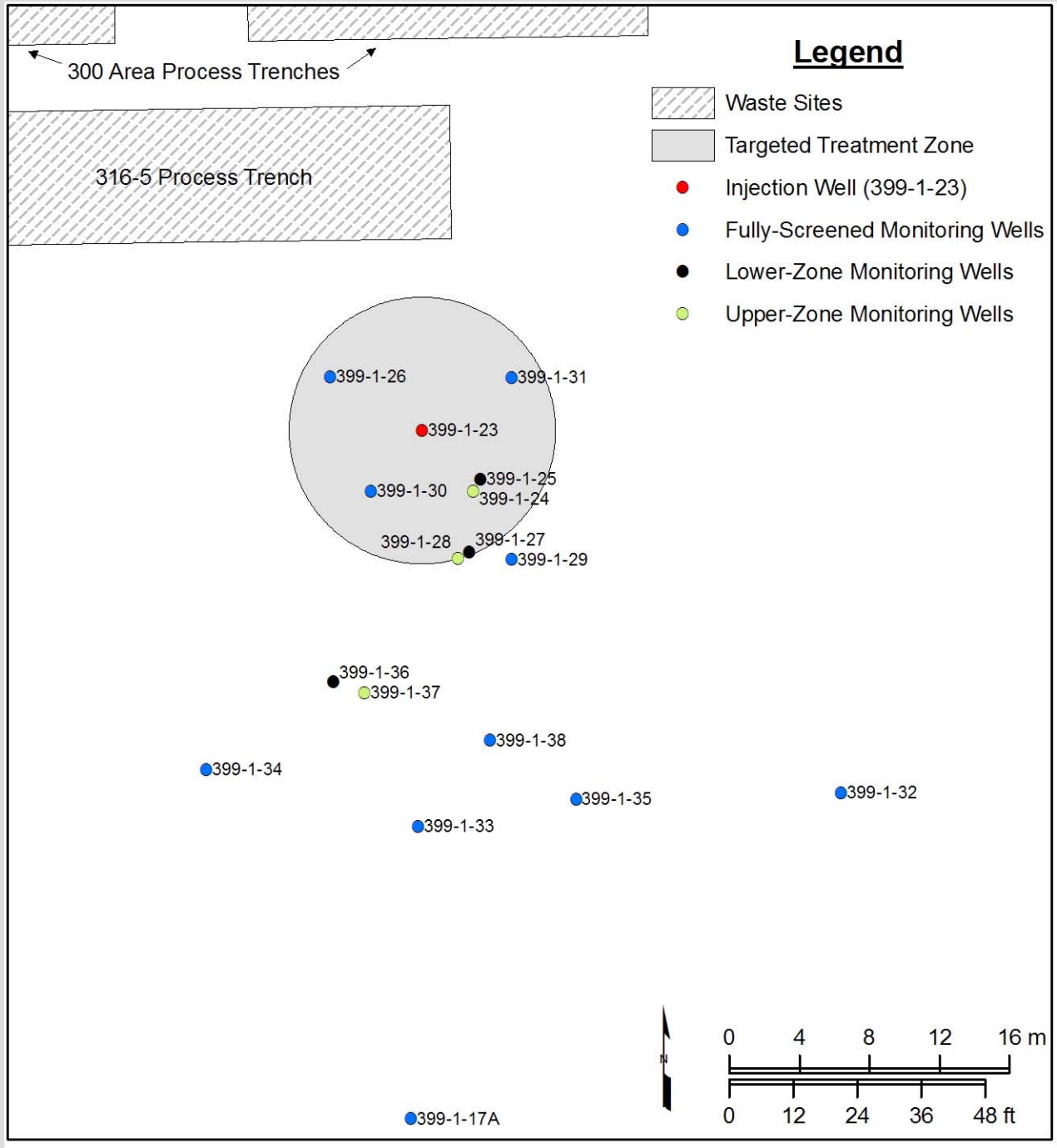
- Bench-scale studies
  - Amendment formulations finalized
  - Phased treatment approach selected
- Site specific characterization
  - Installation of well network
  - Hydrogeologic characterization
  - Hydraulic/tracer injection testing
- Polyphosphate injection design
  - Development of local-scale flow and transport model
  - Determination of injection volumes, rates, and chemical mass requirements
- Polyphosphate injection test
  - Injection conducted in June 07
  - Preliminary performance assessment monitoring

Treatability Test Site Location



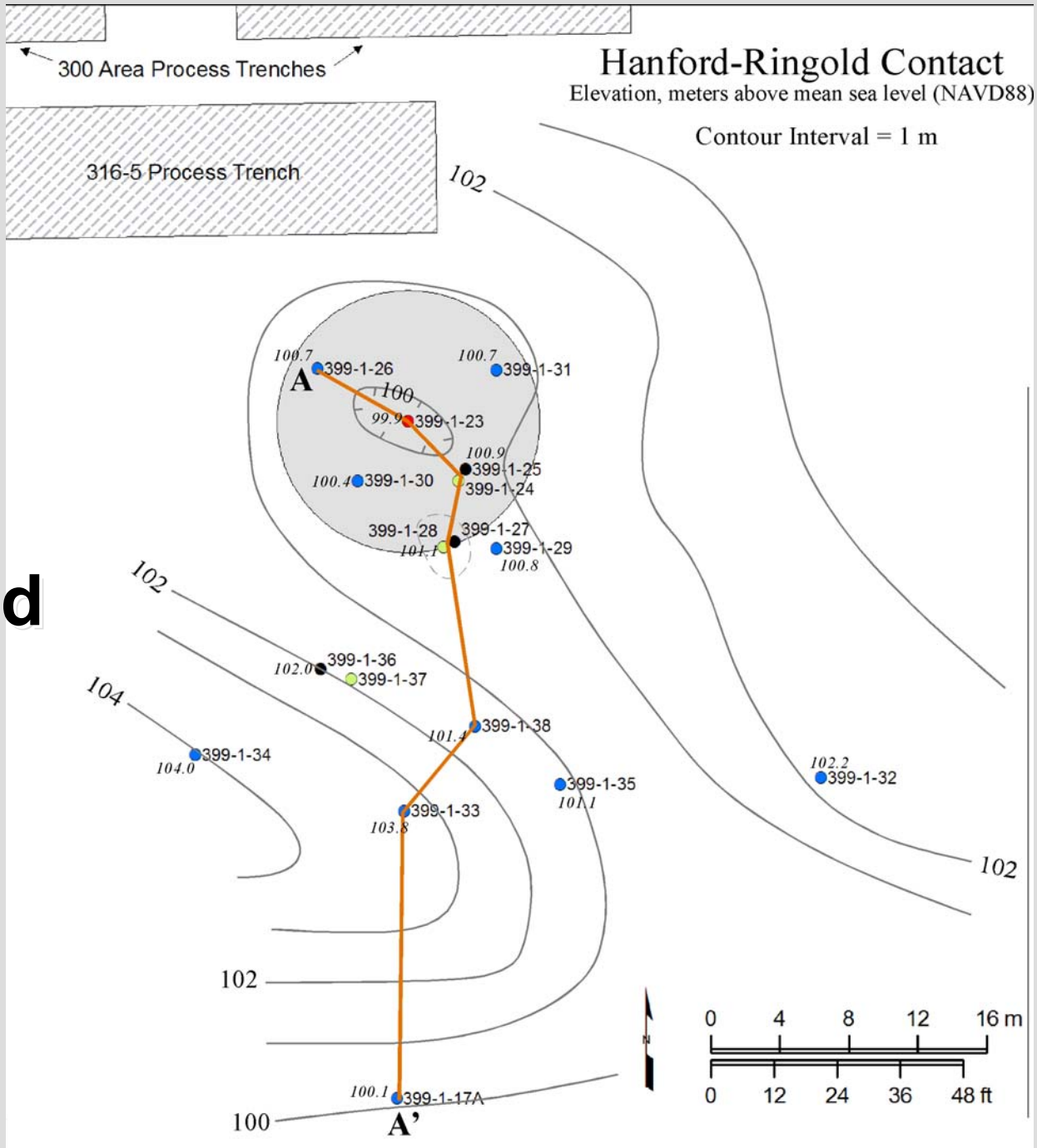


Polyphosphate Treatability Test site Well Layout



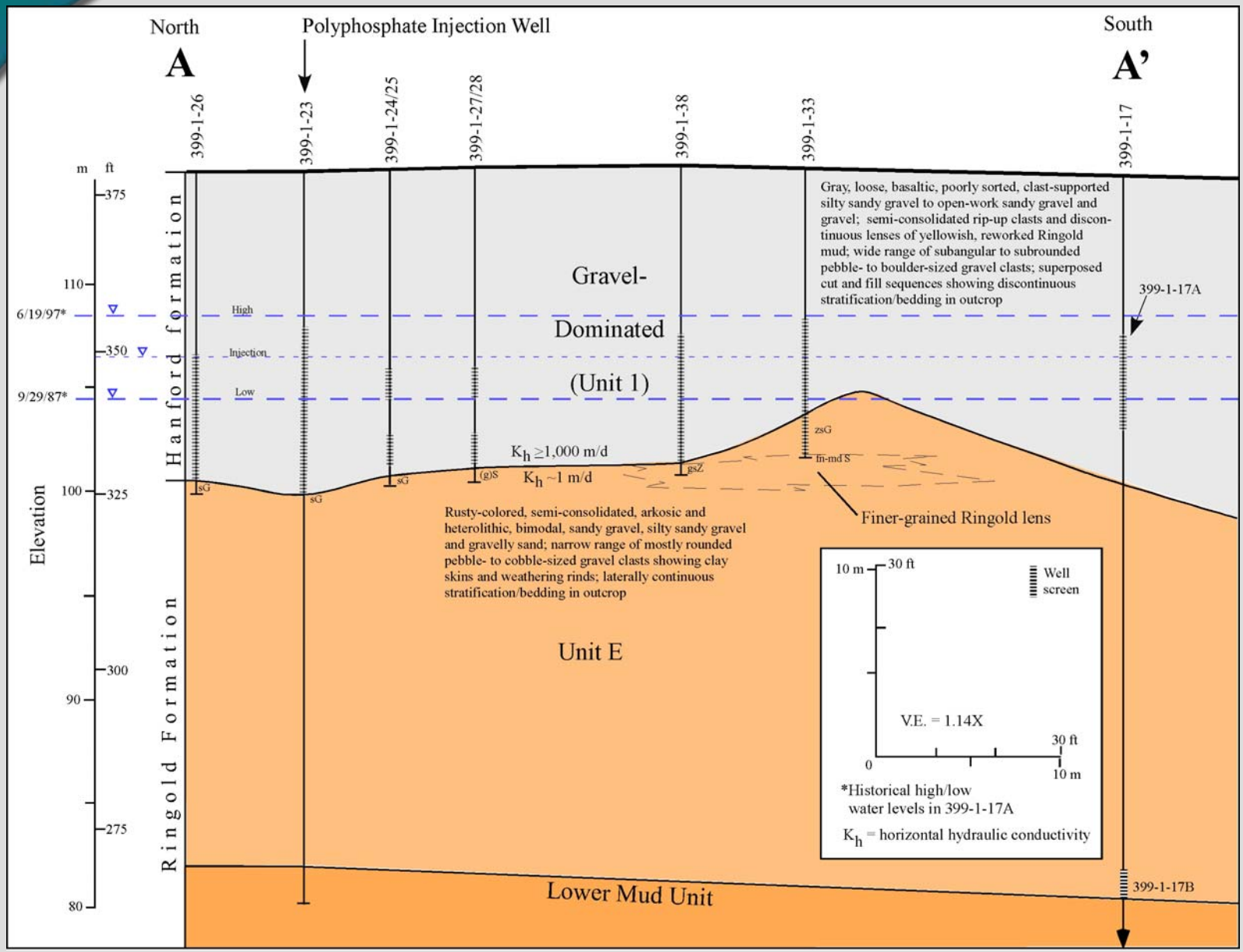
Battelle

Contour Map Showing Hanford-Ringold Contact



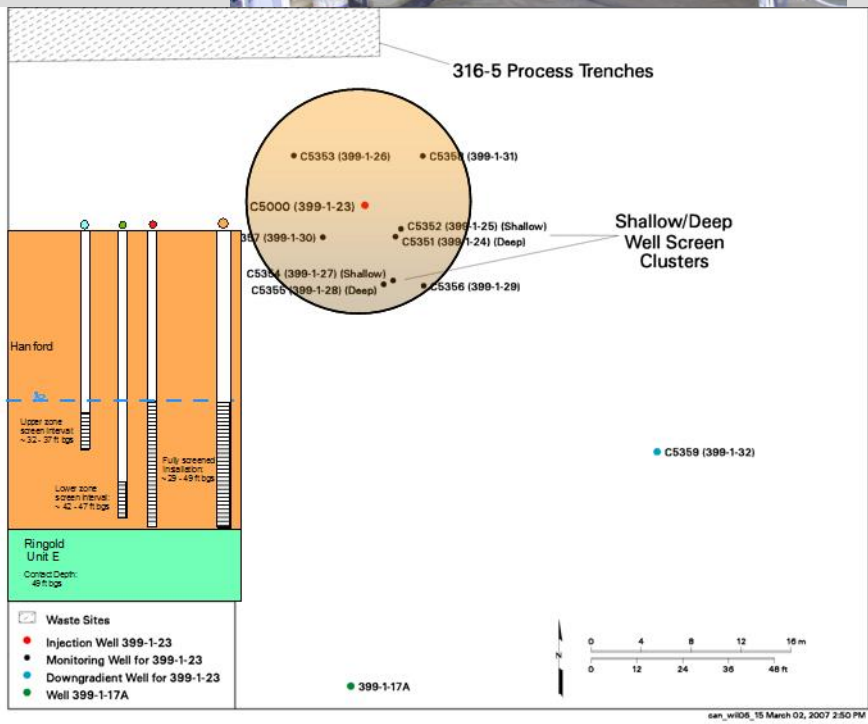
Battelle

Geologic Cross Section



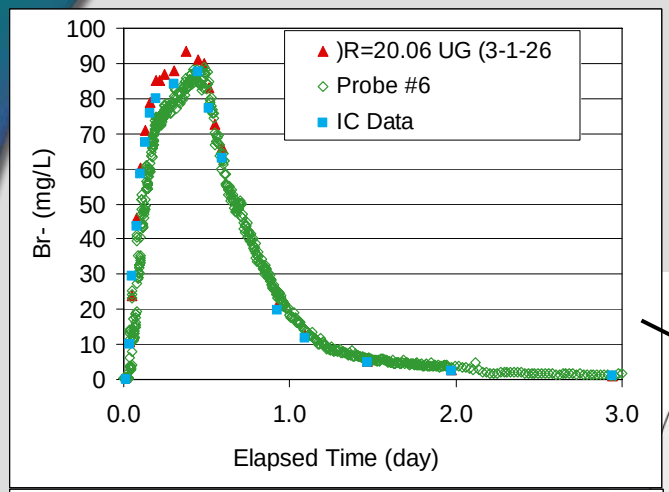
300 Area Polyphosphate Treatability Test Tracer Injection Test

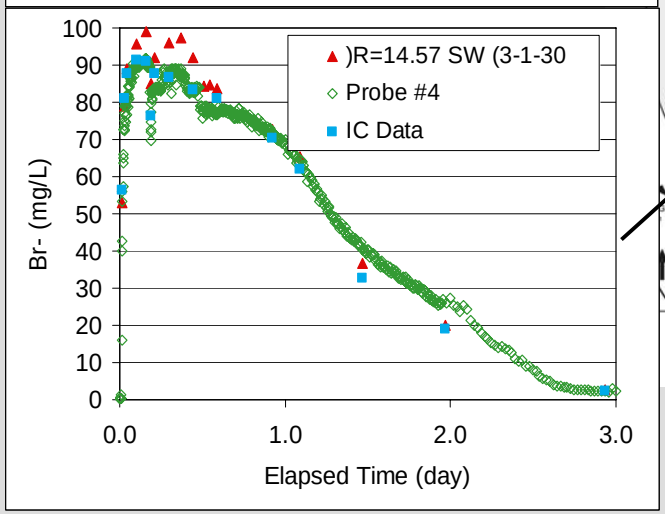
- NaBr tracer test on Dec. 13, 2006
  - Aquifer thickness ~ 15 ft
  - Injection Volume: 143,000 gallons
  - 200 gpm for 11.9 hrs
- Inline tracer mixing with water from Well 399-1-7 (620 ft DG)
- Br^- conc. measured in injection stream and surrounding monitoring wells
  - Samples analyzed on site with ISE
  - Archive samples→ verification by IC
  - Downhole ISE probes installed in all monitoring wells

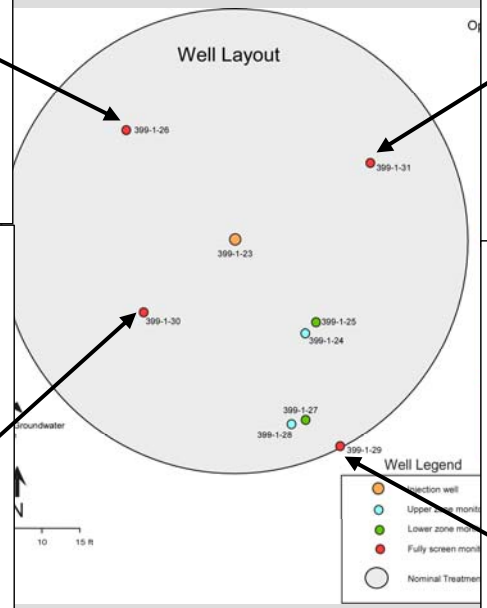


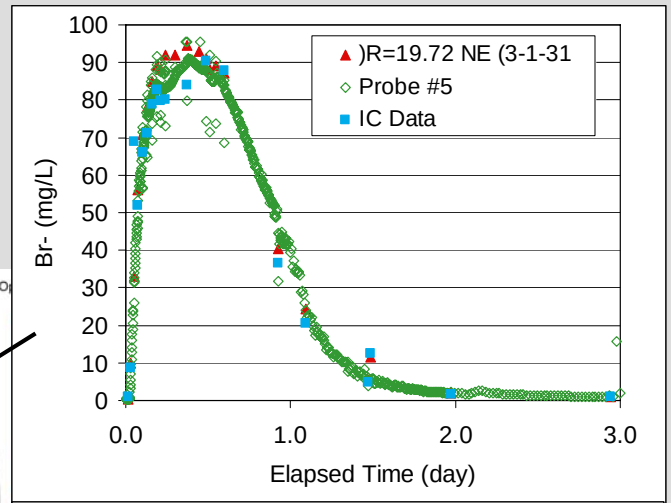
Battelle

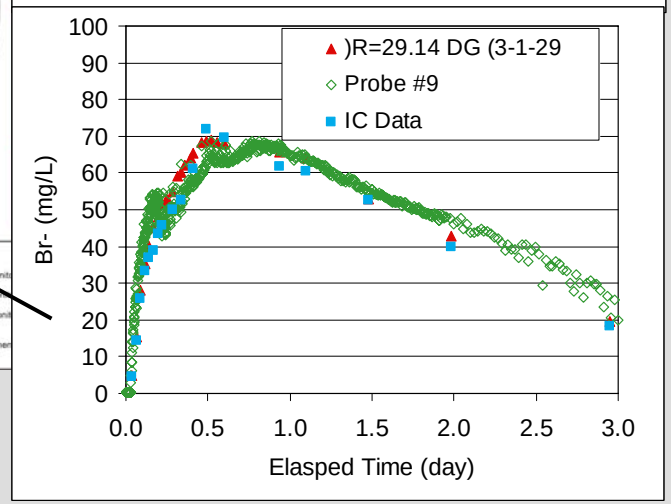
Tracer Test Results within Targeted Treatment Volume





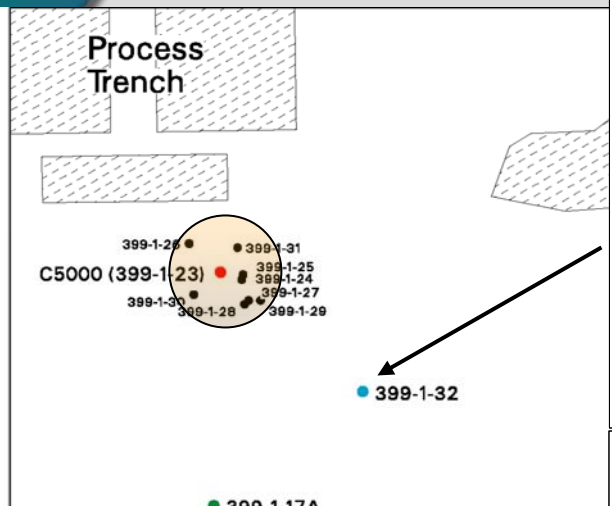






- $\bar{n}_{eff}$ (based on tracer arrival)= 0.18
- Consistent with LFI porosity estimates based on physical property analysis

Tracer Results for Downgradient Wells 399 1-32 and 399-1-7

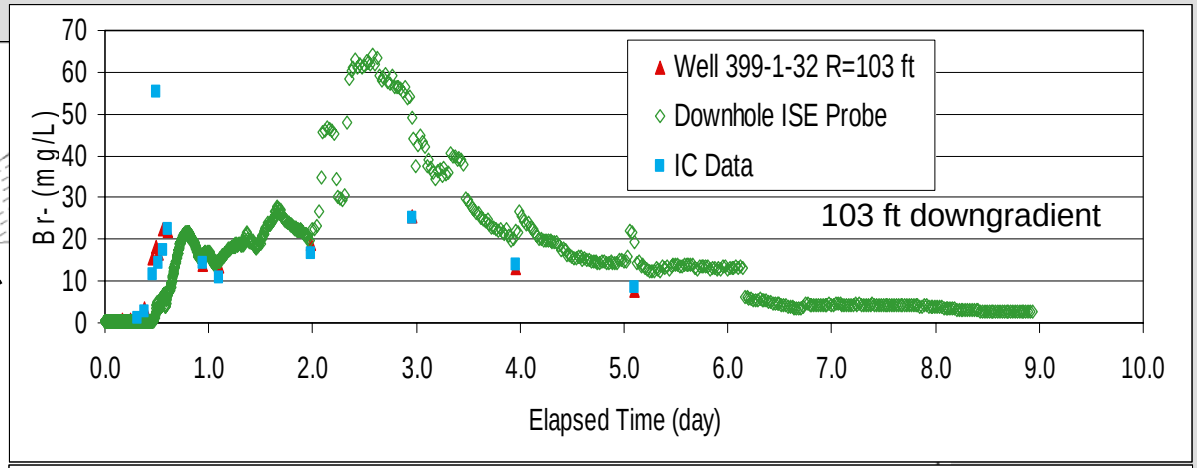


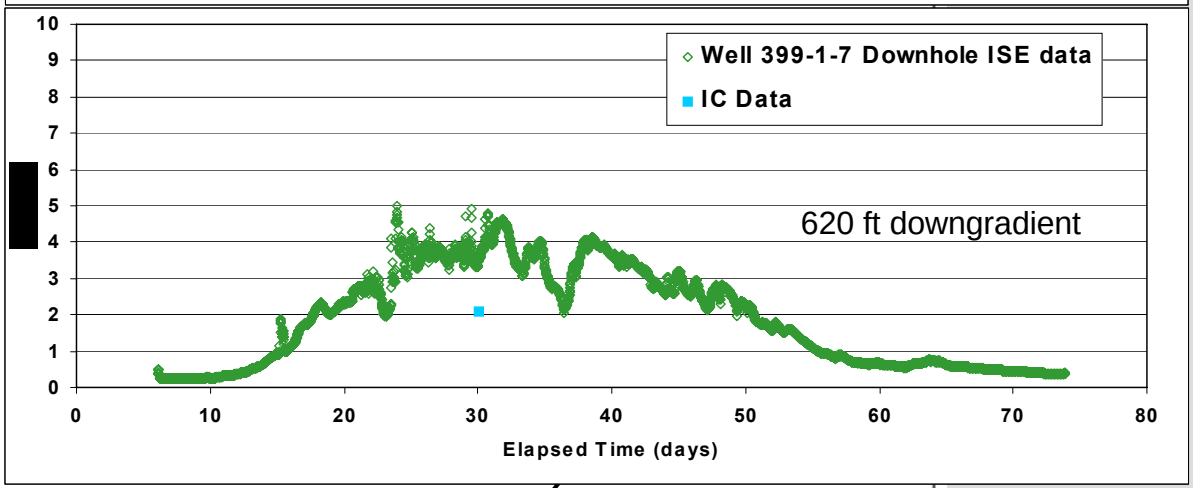
399-1-32 tracer drift data

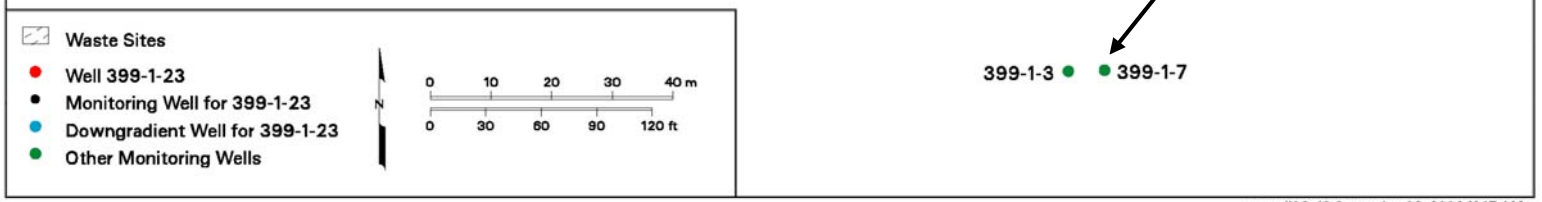
- Arrival in ~ 2 days
- v = 50 ft/d (15 m/d)
- K = 14,000 ft/d (4,300 m/d)
- K_{fast} = 20,000 ft/d (6,100 m/d)

399-1-7 tracer drift data

- First arrival after ~ 12 days
- Tracer plume well dispersed







Treatment Volume Estimation

- Idealized $PV_{25\ ft}$ ~ 42,000 gal
- Tracer arrival data normalized to 25 ft radius based on volumetric ratio
- Injection volume requirements:

Well Name	Distance to 399-1-23 (ft)	50% tracer Arrival (gal)	80% tracer Arrival (gal)	90% tracer Arrival (gal)	100% tracer Arrival (gal)
399-1-23	0.0				
399-1-24	14.5	77,425	125,072	148,895	339,481
399-1-25	14.1	25,093	50,185	62,731	138,009
399-1-26	20.1	34,175	62,136	86,990	201,940
399-1-27	24.1	----	----	----	----
399-1-28	24.3	46,659	95,438	125,130	151,216
399-1-29	29.1	45,640	104,973	----	----
399-1-30	14.6	11,785	17,677	23,569	58,923
399-1-31	19.7	28,941	61,099	77,177	112,550
Average		**38,531**	**73,797**	**87,415**	**167,020**
Avg. @ high WT		**48,292**	**92,492**	**109,561**	**209,332**

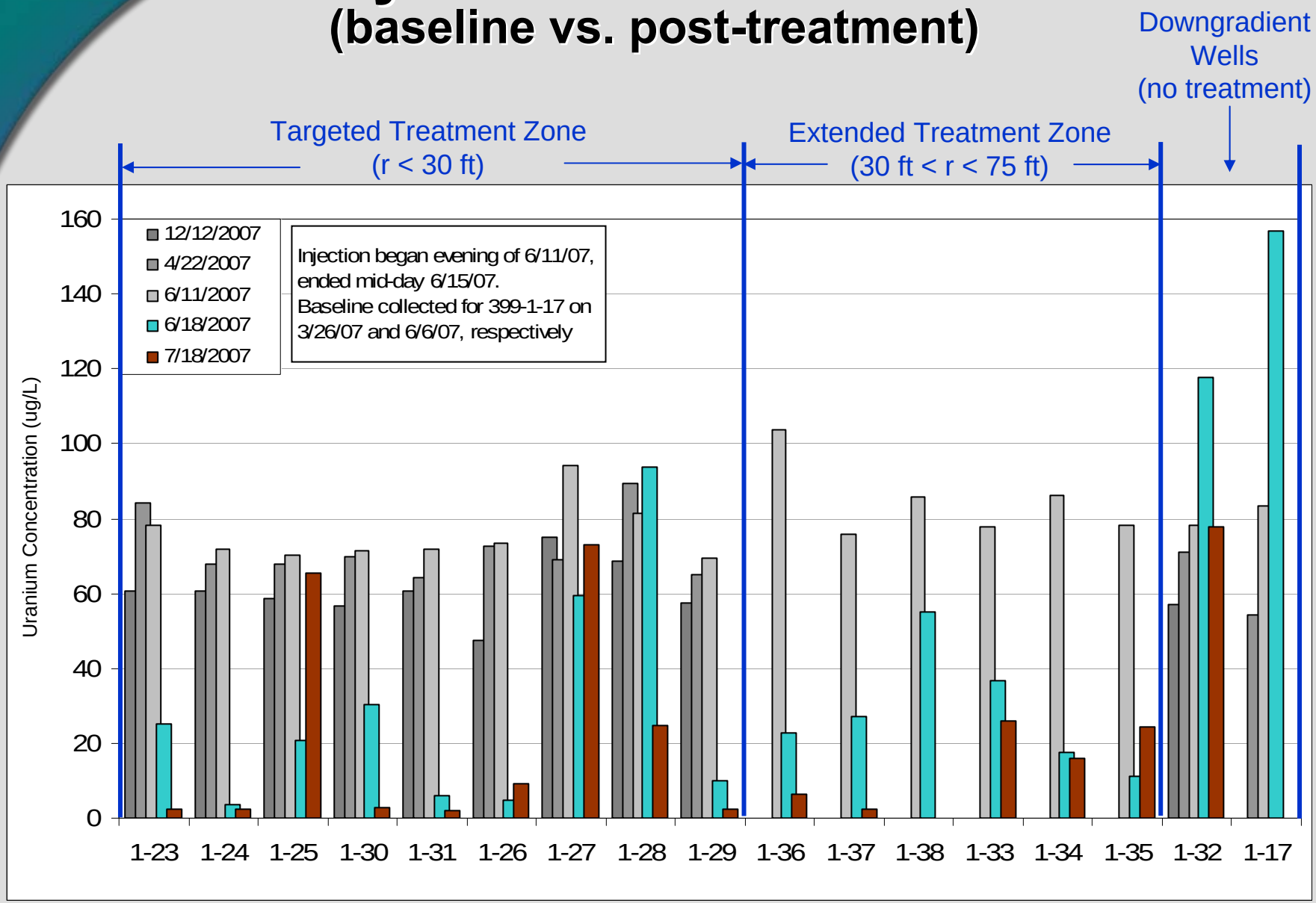
- Amendment volumes adjusted to account for adsorption: R_f $[PO_4]$ ~ 2.4, R_f [Ca] ~ 4.8

Polyphosphate Injection Test

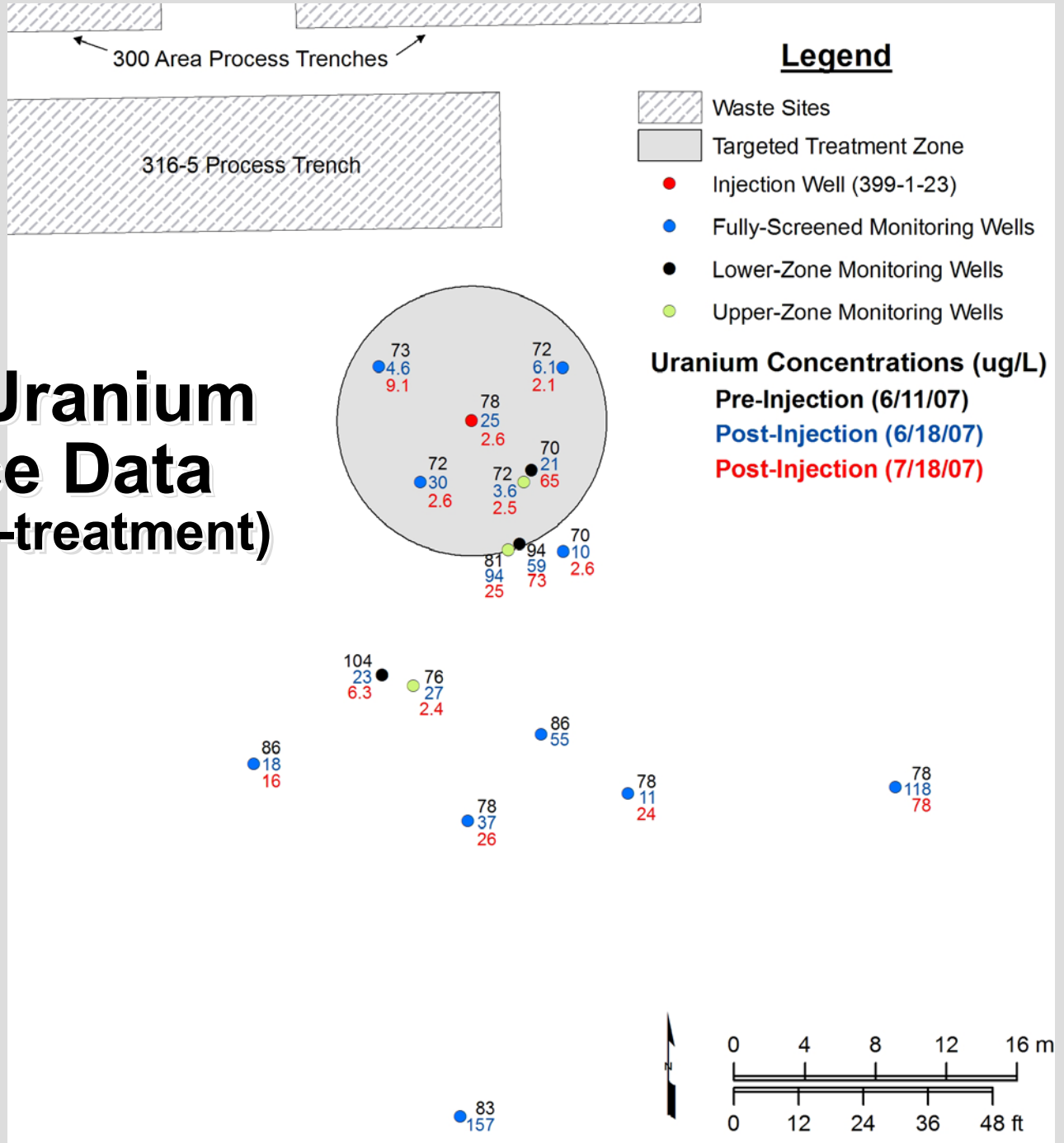
- Polyphosphate injection on June 11-15, 2007
  - Aquifer thickness ~ 19 ft
- 3 phase approach: $PolyPO_4$ / CaCl / $PolyPO_4$
  - 200 gpm injection Rate
  - Amendment injection volumes (Kgal): 250 / 500 / 250
- Amendment Formulation:

Injection	Amendment	Formula	Conc., (g/L)	Conc., M
1	Sodium Orthophosphate	NaH_2PO_4	0.5925	4.94×10^{-3}
	Sodium Pyrophosphate	$Na_4P_2O_7$	0.657	2.47×10^{-3}
	Sodium Tripolyphosphate	$Na_5P_3O_{10}$	1.209	3.29×10^{-3}
	Sodium Bromide	NaBr	0.103	1.00×10^{-3}
2	Calcium Chloride	$CaCl_2$	3.405	3.07×10^{-2}
3	Sodium Orthophosphate	NaH_2PO_4	0.5925	4.94×10^{-3}
	Sodium Pyrophosphate	$Na_4P_2O_7$	0.657	2.47×10^{-3}
	Sodium Tripolyphosphate	$Na_5P_3O_{10}$	1.209	3.29×10^{-3}
	Sodium Bromide	NaBr	0.103	1.00×10^{-3}

Preliminary Uranium Performance Data
(baseline vs. post-treatment)



Preliminary Uranium Performance Data
(baseline vs. post-treatment)



Battelle

Summary

- Initial groundwater performance monitoring data looks promising
- U concentrations lowered to below MCL in most wells within a radial distance of 75 ft
- Additional data/evaluation is needed to assess poor performance at two lower zone monitoring wells
- Core samples scheduled for collection in Oct/Nov will provide more definitive performance assessment data